Document Approval:

	Date Approved
Originator: Chris Adolphsen, RF Technical Lead	7/10/14
Approver: Jose Chan, Accelerator System Manager	7/10/14
Approver: Marc Ross, Cryogenic System Manager Signed via Email	7/15/2014
Approver: Tor Raubenheimer, Physics Team Lead	7/21/14
Approver: David Schultz, Project Technical Director	7-21-14

Revision History

Revision	Date Released	Description of Change
R0	7/21/2014	Original release.

1 Purpose

This document summarizes the physics driven RF system and LLRF requirements for the 1.3 GHz cavities in the SCRF linac that are driven by individual solid-state amplifiers (SSAs). The 3.9 GHz cavities are likewise driven by individual sources (3 kW klystrons in this case), and the field regulation requirements are essentially the same (they are discussed in the SCRF 3.9 GHz Cryomodule PRD). A separate PRD (Klystron Based RF System and LLRF Requirements) will cover the requirements for the groups of 48, 1.3 GHz cavities powered by 300 kW klystrons.

2 Scope

The LCLS-II linac includes 35 cryomodules that each contains eight, 1.3 GHz, Tesla-style superconducting cavities. Forty of these cavities will be powered by stand-alone CW SSAs, which include an AC to DC power supply, RF drive distribution to internal amplifier modules, amplifier output power combiners (e.g., connections to antenna in WR650 waveguide) and a control/monitoring system. This document describes the basic requirements of the RF system in establishing the cavity RF fields that will accelerate the LCLS-II beam. The tight regulation of the fields will be achieved by both RF-based (>0.1 Hz) and beam-based (<0.1 Hz) feedback control. The RF control is part of the LLRF system, whose basic requirements are described in the last section.

3 Definitions

Terms defined within the text.

4 References

LCLSII-2.4-PR-0041	Linac Requirements PRD
LCLSII-4.1-PR-0097	SCRF 3.9 GHz Cryomodule PRD

5 Responsibilities

Marc Ross	Cryogenic System Manager
Jose Chan	Accelerator System Manager
Karen Fant	Linac Control Account Manager
Hamid Shoaee	Electron Controls System Manager

6 SSA Requirements

6.1 SSA Power Output

The required SSA output power depends on the cavity and beam parameters. The basic requirement is that a 16 MV/m on-crest gradient is achievable with the maximum 300 uA beam current. The power must also compensate for any cavity detuning, and the current spec assumes that up to 10 Hz will remain with piezo actuator suppression. A Qext of 4.12e7 was chosen for the cavity coupler to minimize the power for this 10 Hz detuning. To achieve 16 MV/m with a 300 uA beam and this detuning and Qext, 5.72 kW of RF power is required at the input of each cavity.

Power must also be provided to account for the 6% losses in the aluminum WR650 waveguide that will connect each SSA in the Klystron Gallery to a cavity power coupler in the tunnel (see below). With an additional 10% for tuning overhead, the maximum SSA output power needs to be 6.8 kW. For initial LCLS-II operation with beam currents up to 100 uA, 3.8 kW will be required.

The actual overhead will typically be larger as the detuning and cavity gradients will be lower than the worse cases assumed above. Also, there is overhead in the beam energy feedback system that will compensate any deviations of the net energy gain in each portion of the linac.

6.2 SSA Regulation and BW

The RF from the SSAs running ‘open loop’ needs only moderate regulation compared to the closed loop regulation of the cavity fields discussed below. Although the cavity BW is only about 30 Hz, the effective BW of the RF station operating in closed loop will be around 70 kHz. The SSAs need to have a delay-line-like transfer function to allow maximum gain in the control feedback loop. Specifically, the SSAs are to have a small signal, 1 dB BW (two tone measurement) of 1 MHz or wider with a transfer function that is amplitude flat (< 5%) and phase linear (< 5 degree deviation) within 100 kHz of the nominal frequency. The latency through the SSA should be < 300 ns.

Also, the SSA noise figure is to be less than 10 dB, the nominal maximum power is to be achieved with < 1 dB compression and the harmonic power output is to be less than -30 dBc.

6.3 SSA Efficiency

The AC to RF efficiency goal for the SSAs at the rated power is to be at least 45% (currently 35%-40% is achievable, but vendors believe 45% is possible in the near future). The drain voltage should be controllable (although not automatically) with the goal that the efficiency at half of the rated power is at least 40%.

6.4 SSA Reliability

The reliability of the SSAs needs to be such that less than 3% of them fail per year and other failures that disable the unit do not occur more than once on average per 5 years.

7 Waveguide

A water-cooled isolator is required just after the SSA output port that will absorb the full SSA output power if reflected from the cavity. WR650 waveguide will be used to transport the RF from the gallery to the tunnel via the existing 27 inch diameter penetrations that are spaced about every 20 feet along the linac (four waveguides per penetration). Three-inch coax cable is also being considered, but the cable currently available is not radiation-hard, and due to its power limits, would require the isolators to be located just before the cavity couplers in the tunnel. It would also increase the RF transport losses from 6% to 11%.

The waveguide will not be water cooled but will be pressurized just above atmospheric pressure for interlock purposes (a drop pressure will inhibit power from the associated SSA). The transport line needs to include a directional coupler with 30 dB or better isolation just before the cavity couplers.

8 Low Level RF

The Low Level RF (LLRF) system provides the drive for the high power RF systems and monitors/measures the cavity fields and forward and reflected power. The primary purpose of the LLRF system is to provide the field regulation of the superconducting cavities as described below. In addition, it provides the EPICs control system interface to the RF system. The LLRF system is also responsible for the following functions:

- Resonance Control (Stepper and Piezo tuner)
- Coupler Control (Stepper)
- Cavity/Cryomodule RF Interlocks
- Phase Reference System

Finally, the LLRF system will provide interfaces to the timing, machine protection and beam feedback systems.

For the cavity gradient regulation, the LLRF system will use a control algorithm embedded in a field programmable gate array (FPGA). The control algorithm allows for high gain at low frequencies which assures zero steady-state error between the set-point and the cavity voltage. Accounting for latency (< 1.5 us is expected) and all noise sources (e.g., digitization noise, phase noise in local oscillators, etc.), the requirement is to regulate the RF field in each cavity to 0.01% in amplitude and 0.01 deg in phase on a fast time scale (>0.1 Hz) in the presence of beam current variations (< 1% for currents up to 300 uA) and microphonics (< 10 Hz with piezo-actuator control) for cavities operating at 16 MV/m with loaded Q's of 4e7. Systematic effects such as calibration errors and phase drifts in cables need to be compensated as well. It is expected that the beam-based energy and bunch length feedback loops will correct for variations below about 0.1 Hz.

To limit the cavity detuning variations, especially from He pressure fluctuations, slow (up to a few Hz) cavity resonance control will be implemented based on the phase difference between the forward RF and cavity RF signals. Piezo-actuators will be used for this purpose, at least two in each cavity tuner (one serving as spare) with a setting accuracy of no more than 1 Hz level. The remaining detuning will depend on the magnitude of the high frequency portion of the detuning spectrum, which has proven difficult to compensate (although R&D will be done to try extending the frequency range of the piezo-actuator microphonics suppression). The cavity resonance control must be careful not to worsen the phase and amplitude regulation beyond the tolerances given above.

Wong, Theresa

From: Ross, Marc C.
Sent: Tuesday, July 15, 2014 3:33 PM
To: Wong, Theresa
Cc: Ross, Marc C.
Subject: RE: NEED APPROVAL - PRD "SSA Based RF Power and LLRF Requirements" (LCLSII-4.1-PR-0098)
Attachments: RF_LLRF_SSAPRDmcr.pdf

Theresa -

Done. With two small changes. See 'sticky notes'.

Attached.

Approved.

Marc

-----Original Message-----
From: Wong, Theresa
Sent: 14 July 2014 18:57
To: Ross, Marc C.
Cc: Wong, Theresa
Subject: FW: NEED APPROVAL - PRD "SSA Based RF Power and LLRF Requirements" (LCLSII-4.1-PR-0098)
Importance: High

Hi Marc,

Need your signature on the attached document.

Thanks,

Theresa

From: Wong, Theresa
Sent: Tuesday, July 08, 2014 3:50 PM
To: Adolphsen, Chris E.; Chan, Jose Quim; Ross, Marc C.; Raubenheimer, Tor O.; Schultz, David C.
Cc: Wong, Theresa; Marsh, Darren S.
Subject: NEED APPROVAL - PRD "SSA Based RF Power and LLRF Requirements" (LCLSII-4.1-PR-0098)